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A study of subsurface vapor intrusion from exploration & production waste

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A STUDY OF SUBSURFACE VAPOR INTRUSION FROM EXPLORATION & PRODUCTION WASTE

A thesis

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ABSTRACT

Expanding city growth is causing the inhabitants of Louisiana to move further into rural areas. Abandoned oil and gas production sites are being used for residential and light commercial purposes. This thesis will attempt to determine if known benzene levels in Exploration and Production (E&P) waste will be harmful to human health via subsurface vapor intrusion into the newly developed residential and light commercial structures. Louisiana does not currently regulate benzene during the closure of pits that contained E&P waste. Current pit closure techniques warrant testing for benzene Based on current Louisiana legislation, benzene contamination of groundwater is currently the most protected human exposure route to benzene from E&P waste. Indoor air emissions from benzene in E&P waste in the soil must be studied to determine the risks associated to developing residential properties on abandoned exploration and production sites.

Exploration and Production waste is described in Louisiana Administrative Code (LAC) 43:Part XIX. Section 129.B as "drilling wastes, salt water, and other wastes associated with the exploration, development, or production of crude oil or natural gas wells and which is not regulated by the provisions of, and, therefore, exempt from the Louisiana Hazardous Waste Regulations and the Federal Resource Conservation and Recovery Act." The constituents of concern tested in soil and groundwater, which are currently regulated by Statewide Order 29-B for pit closures are chlorides, petroleum hydrocarbons, and metals.

Previous studies of E&P waste are used to determine the characteristics, concentration, and potential harm from benzene to human health found in E&P wastes. These studies were funded by the State and are used in this thesis to provide Louisiana

related data. These previous studies of E&P waste are also used as baseline references for known benzene concentrations in E&P waste. A risk assessment outline established by F.B. Thomas in combination with the calculations provided by the Johnson and Ettinger Model (1991) for Subsurface Vapor Intrusion into Buildings are used to estimate the risk of the indoor air exposure to benzene vapors remaining in the soil from closed E&P waste pits.

EXPLORATION AND PRODUCTION REGULATION HISTORY (1900-1950)

The need for regulation of oil and gas production activities was first realized after the first production well discovery was completed in the Jennings field in 1902. It was not until May 1905, did lawmakers take a serious look at the emerging oil and gas industry. This was due to a blow out in the Caddo Field from a gas well. The need for conservation and protection of the States natural resources was acknowledged. Act 71 was passed in 1906 stating "...it is a criminal offense to allow a gas well to remain out of control, or to burn or blow into the air wastefully the natural gas from any well." The Act also authorized the taking over of a neglected wild well. This was the beginning of an evolving regulation of the oil and gas industry. (Fourteenth Biennial Report (938-1939, 14:7).

The declaration from the Conference of Governors dated May 13-15, 1908 states that the great prosperity of the country is dependent upon its resources. The declaration continued by recommending the passage of laws and regulations to prevent waste of mining in the extraction of coal, oil, gas, and other minerals. The 1910 Louisiana Conservation Commission Report (Report of 1910, 3) recommended that laws be put in place to conserve, protect the life of the people, and the protection of life in the mines.

In accordance with the Conference of the Governors, the Louisiana Commission for the Conservation of Natural Resources, known thereafter as the Commission, was established by the Legislature (Acts 1908, No. 144) and was done so to regulate the rapid consumption of the precious resources of Louisiana. The goal of conservation as defined by the Commission was to inventory the resources of Louisiana, educate the public on the necessity of conservation, and to regulate the use of natural resources through legislation (Report of 1910,2). The 1910 Louisiana Conservation Commission Report (Report of 1910,7) states that Section 2 of Act No. 144

required the Commission to research and report the on condition of the forests, on climate conditions and control of water ways, on drainage of swamp land for reclamation, and on prevention of waste from the exploration and production of oil, gas, and other minerals. The recommendation of legislation relating to natural resources was a vital function of the Commission's duties.

The Report of the Louisiana Conservation Commission of 1910 (Report of 1910, 9) also states that in 1908 the Maine Supreme Court set precedent by stating the property rights of individuals is superseded by the rights of the community in response to a question by the Maine legislature. The first reason for the decision was that "...such property is not the result of productive labor, but is derived solely from the State itself, the original landowner." The second reason was that "...the amount of land being incapable of increase, if the owners of large tracts can waste them at will without State restriction, the State and its people may be helplessly impoverished, and ne great purpose of government defeated ..." (Report of 1910, 9). This decision was then followed by the Court of Errors and Appeals of New Jersey which was upheld by the Supreme Court of the United States. Chief Justice Holmes wrote "The State has a standing in Court to protect the atmosphere, the water and the forest within its territory, irrespective of the assent or dissent of the owners of the land most immediately concerned." Due to these rulings, the Commission believed that "...the remedy against waste and destruction..." lies within legislation and most importantly, the education of the public. (Report of 1912, 19)

The Report of the Louisiana Conservation Commission of 1912 continued to pursue means to better regulate the conservation of our natural resources. As written in a Letter of Transmittal to Governor Jared Y. Sanders, the Acts of the 1910 Legislature greatly reinforced the objectives of the Commission. Act No. 254 of the 1910 Louisiana Legislature created the Department of Mining and Minerals which enabled the Commission through regulation "...to

control the production of oil and gas and of minerals and mines, all with the purpose of conserving these natural resources, preventing unnecessary waste in their production" (Report of 1912, 4). Funding was provided by the promulgation of Act No. 196 with the purpose of "...levying a tax upon the business of severing natural resources, particularly with reference to the business of severing oil and gas, salt, sulphur, and timber". The Commission also believes that the constitutionality of severance taxes enacted by Act No. 196 would be verified under Article No. 229 of the Constitution of 1898, which was amended in 1910 (Report of 1912, 6). The commission believed exploiting natural resources comes with a price and a fraction of that price is the funding of the resources necessary to regulate the exploitation. The Commission issued two new principles of government, which are the foundations for later actions (Report of 1912, 10).

1. He who severs, and profits by exhaustion of, the natural resources of the State, in the creation of which he had no hand, should, in addition to the common burden of the expense of government, borne by all alike, bear an additional burden of taxation, the proceeds to go towards replacing either the resource which he has removed, or if that be impossible, toward renewing one which by its nature is renewable.

2. That the controlling influence in human affairs, official and unofficial, must for the sake of the safety of government and society, be to a measurable extent, reverse our former course, and, apparently, at least, build up the country at the expense of the cities and industrial centers, instead of building up the cities and industrial centers, at the expense of the country.

To further display the authority of the Government, Act No. 127 of 1912 created the Conservation Commission of Louisiana, which is now the Department of the Natural Resources (Report of 1914, 5). Inaugurated on August 27, 1912, the duties of the Commission are to preserve and control all of the States natural resources and to bring the people a greater knowledge and respect of those resources. This was proposed under the assumption that the

people, with a newfound appreciation for the States natural resources, would support the Commission in the enforcement of the laws. (Report of 1912, 6)

The Conservation Commision of Louisiana became The Department of Conservation (Department), as a result of Act No. 66 of 1916 (Biennial Report 1918, 5). The new Department was given the duties of not only ensuring all laws pertaining to regulating natural resources are followed, but also to improve, enlarge, and conserve. The Department was divided into subdivisions, to allow for better regulation of each resource. The resources included mines and minerals, forestry, fisheries, game and other wildlife, and oysters. (Biennial Report 1918, 5)

The Mines and Minerals division was given the duty of implementing conservation techniques to conserve oil and gas reserves. The division was given the task of supervising all mining operations to prevent waste from the drilling and transport practices under Act No. 254 of 1910. The Fourth Biennial Report 1918-1920, strengthened Act No.190 of 1910 by stating that all oil and gas be properly restricted to pipes and the proper receptacles within two days after a well began producing (8). They were also given the task to regulate the storage of oil due to the lack of infrastructure. Storing oil in earthen reservoirs mitigated the lack of transport and storage (Fourth Biennial Report, 4:8).

Permitting was also regulated by Department rules. The issuing of permits for the deepening and pulling of oil and gas wells allowed for better tracking. Permits allowed the Department to gain valuable information pertaining to the activities of the operator. This also allowed the state to take the proper precautions with regards to all new activities related to the extraction of oil and gas (Fourth Biennial Report, 4:33). The Departments enforcement capabilities were solidified in 1921, as stated in The Sixth Biennial Report (1922-1924) by becoming constitutionally a branch of the executive department of state government (6:10).

The Seventh Biennial Report, 1924 – 1926 (Seventh Biennial Report, 7:37), reported a concern for the pollution of the States streams. Bayou Dorcheat was tested due to pollution by oil field wastes and other sources. Chemicals being used in oil fields were found present in the water. The constituents of concern included chlorides and tretolite, the latter was used to emulsify the oil and water (Seventh Biennial Report, 7:38). Also present was a reddish precipitate, which gathered on the fish's gills, and was a contributor to lowered dissolved oxygen in the water. These findings created the necessity for oil operators to impound waste water for treatment before releasing it into streams. Act No. 133 of 1924 gave the Department the authority to cease any pollution that "killed the fish life" (Seventh Biennial Report, 7:37). Act No.133 was one of the first acts to recognize the pollution from oil and gas production.

The pollution of oyster beds was a major topic in the Thirteenth Biennial Report, 1936 – 1937 (Thirteenth Biennial Report, 13:13). Discharge from industrial plants, oil and a gas extraction, and sub-surface salt water exacerbated the pollution problem. The continued complaints from oystermen resulted in another study concluding that the complaints were unfounded and the oil and gas industries were taking the proper precautions to prevent pollution. Sub-surface disposal of salt water into the sand strata, because of the sufficient porosity greatly reduced the problem of discharged produced salt water into rivers and streams (Thirteenth Biennial Report, 13:13).

The Fifteenth Biennial Report, 1940 – 1941 (Fifteenth Biennial Report, 15:209), classified water generated by oil and gas production. Water produced through defects in the casing was defined as top water. The water, which occurred between the oil reservoir and confinement, was referred to as intermediate water. Edge water was defined as the water in the lower areas of an oil-bearing formation. The last classification of water was the bottom water.

This portion of the water lies under an oil deposit and is separated by an unyielding layer (Fifteenth Biennial Report, 15:210).

EXPORATION AND PRODUCTION PIT REGULATIONS (1950-CURRENT)

Section XV according to Amendment to Statewide Order No. 29-B (Amendment 1967, 1) an amendment to Title 30, Section XV, Statewide Order No. 29-B was amended on November 1, 1967 to effectively change the name of Section XV to "Pollution Control" and to expand requirements to permit pollution. Waste oil and oil field waste was prohibited from being discharged into any stream, lake or other body of water. The oil waste could not be discharged into any drainage system that would lead directly into any water body. This Amendment was deemed necessary because the pollution by the waste oil and oil field waste was determined not to be in the interest of the public (Amendment 1967, 1). The Department of Conservation was required to approve the disposal of the waste into waste pits, subsurface injection, and tidal waters deemed undrinkable. A 1974 amendment to Statewide Order No. 29-B allowed saltwater to be disposed of into pits approved by the Commissioner of Conservation (Statewide Order Governing the Drilling For and Producing of Oil and Gas in the State of Louisiana, August 26, 1974, 13).

A 1986 amendment to Statewide Order No. 29-B was the first comprehensive oilfield pit regulation for Louisiana (Amendment 1986, 13). This Amendment officially defined the different types of pits and the waste stored in them. Contamination was also defined creating an acceptable baseline contamination level in soil and groundwater for remediation to be protective of human health. The Amendment charges the Commissioner of Conservation with the regulation of "storage, treatment, and disposal of nonhazardous oilfield waste generated from the drilling and production of oil and gas wells...the construction, operation, monitoring, and closure of pits used to store produced water and other nonhazardous waste..."(Amendment 1986, 1). These requirements were intended to be protective of soil and groundwater.

Section 2.2.G and H, of Statewide Order No. 29-B, as amended in 1986, required all existing pits to with the construction requirements outlined therin. If these pits were to be used for storage of nonhazardous oilfield waste (NOW), the operator was required to document that the proper pot liners were utilized as described in Section 2.1. All pits that did not comply had to be closed in accordance with Section 2.6 and 2.7. Pit closure consists of "...onsite land treatment, burial, solidification or other techniques approved by the Office of Conservation..." Section 2.6 also states that the operator, not the landowner, remains liable for contamination. Metals, pH, oil and grease, and salts are to be tested in the pit contents prior to closure.

In an Amendment to Statewide Order No. 29-B, October 20, 1990, Section XV was formatted to the requirements of the Louisiana Administrative Code. The new designation was Louisiana Administrative Code (LAC) Title 43:Part XIX. Section 129.B (LAC43:XIX.129.B). This amendment also added new barium requirements and passive closure techniques for oilfield pits, and required the closure of production pits. None of these amendments required testing for benzene but did require testing for oil and grease. Benzene was not a constituent of concern because it is natural component of oil produced.

PAST STUDIES OF EXPLORATION PRODUCTION WASTE

The studies discussed in this section allow the author to make assumptions based on measured benzene concentrations from waste produced during oil and gas exploration and production activities. The author will discuss three studies that associate a risk to benzene vapors. These assumptions are needed because Louisiana does not currently regulate benzene for pit closure. Government reports that characterized risk for E&P waste in Louisiana, is the best available information on benzene pertaining to this thesis. The author used information gathered from the Louisiana based and state funded studies to define characteristics of benzene in the States soils. Benzene calculations taken from these studies as well as Statewide Order No. 29-B was used as input values for indoor air modeling.

One such study, entitled: "Phase 3 Report, Risk-Based Evaluation of Exploration & Production Wastes", was submitted to the Louisiana Department of Natural Resources by Dr. F.B. Thomas in September 2000. In the report, Dr. Thomas established risk associated with the handling of exploration and production waste. As discussed in Statewide Order No. 29-B, oilfield production pits are used to store E&P Waste. Such waste is generated in the process of or as a result of the exploration, development, and production of crude oil and natural gas resources. These wastes are exempt under the Louisiana Hazardous Waste Regulations and the Federal Resource Conservation and Recovery Act (LAC 43.XIX.501). These wastes are also classified differently based on the use or type.

Waste Type 01 - Salt Water (Produced Brine)

Produced Brine or Salt Water is produced water with a chloride content of 500 ppm or greater. The water is produced during oil or gas production and contains hydrocarbons and metals. The chlorides or salt is indigenous to formation where the oil and gas is located. The

volume of produced water from a well, occasionally above 90% of the well production, depends on the method of recovery. Biocides, coagulants, corrosion inhibitors, cleaners, dispersants, and emulsion breakers may also be present in produced water due to the various processes used to extract the oil and gas. (Thomas, 21)

Waste Type 02 - Oil-Based Drilling Mud & Cuttings

Oil based drilling mud is used to bring soil cuttings from the downhole auger to the surface. The mud is a thick liquid and also reduces the temperatures in the boring to prevent the drill pipe from sticking. Water-in-diesel oil emulsions are present along with bentonite to control the viscosity of the liquid. (Thomas, 21)

Waste Type 03 - Water-Based Drilling Mud & Cuttings

Water-based muds are naturally occurring materials composed of fresh or saline water. Clays and drilling solids are also present in water-based mud. This type of mud is used to prevent fluid loss, thinning, and weight, to maintain viscosity, and to control pH. Bentonite and barite are also part of the mixture (Thomas, 22).

Waste Type 04 - Drilling, Workover & Completion Fluids

These fluids are used for well completion, treatment, and stimulants. They are comprised of spent hydraulic fluids mainly consisting of fresh or saline water and downhole materials such as pipe scale, sands, and small amounts of metals from drill bits. Concern for contamination is due to petroleum hydrocarbons, organic polymers, and corrosion inhibitors. (Thomas, 22)

Waste Type 05 - Production Pit Sludges

Rigwash, spent completion fluids, and drilling mud and cuttings are all present in production pit sludges. Pits are open to the air allowing the hydrocarbons and solids to volatilize. Some operators introduce microbes to biodegradate the hydrocarbons in the sludge. (Thomas, 22)

Waste Type 06 - Production Storage Tank Sludge

Production storage tank sludge is the accumulated sediments and water that remain in the bottom of crude oil storage tanks. Production separators, fluid-treating vessels, crude oil stock tanks and impoundments are also considered tanks. Hydrocarbons are typically found in the tank sludge and are treated by biodegradation methods. (Thomas, 23)

Waste Type 07 - Produced Oily Sands & Solids

Sand and drilling material are components of produced oily sands and solids. Also present are crude oil, salts, organic polymers, and corrosion inhibitors. (Thomas, 23)

Waste Type 08 - Produced Formation Fresh Water

Some oil and gas is produced from shallow formations that contain fresh water. Therefore, fresh water may be produced with the oil and gas production. The total dissolved solid content of the produced freshwater is less that 500 ppm. Petroleum hydrocarbons, metals, biocides, coagulants, corrosion inhibitors, cleaners, dispersants, and emulsion breakers could also be present. (Thomas, 24)

Waste Type 09 - Rainwater

Rainwater becomes contaminated when it comes in contact with pits containing E&P waste. The rainwater must be treated as waste and disposed of in the same manner. (Thomas, 24)

Waste Type 10 - Washout Water

Wash out water is generated by cleaning E&P Waste transport vessels and is considered exempt because the water and entrained solids is now considered E&P waste. (Thomas, 24)

Waste Type 11 - Washout Pit Water

Washout pit water is an exempt waste when it is used to clean upstream vessels. This waste consists of solids that may contain hydrocarbons. (Thomas, 25)

Waste Type 12 - Gas Plant Waste

Gas plant waste is the commingling of produced water and processing waste from gas plants. (Wilson, 25)

Waste Type 13 - Basic Sediment & Water (BS&W) Waste

Basic sediment and water waste is produced from salvage oil operators. These operators are permitted to only receive waste from oil and gas production. (Wilson, 25)

Waste Type 14 - Pipeline Test Water

Pipeline test water is regulated under Statewide Order No. 29-B because it does not meet discharge limits. The water contains hydrocarbons due to pressure testing and cleaning of the pipeline system. (Wilson, 14-5)

Waste Type 15 - Commercial Facility Waste

Commercial facility waste consists of waste barge loads from commercial transfer facilities, solids from barge wash out, and separated sludge material from wash out water. This waste could also be storage tank bottoms, rainwater, and contaminated soil. This waste consists of 26% of all E&P waste. (Wilson, 26)

Waste Type 16 - Oil Spill Waste

Oil spill waste is material used in crude oil spill clean-ups. (Wilson, 27)

Waste Type 50 - Waste Containing Salvageable Crude / Hydrocarbons

The salvageable waste can either be recovered or disposed. Hydrocarbons and sludge's are present. (Wilson, 27)

Waste Type 99 - Other E&P Wastes

This waste is unidentified waste (Wilson, 27). Wastes not specifically defined in Statewide Order No. 29-B but upon review, are determined to meet the EPA guidelines for RCRA exempt waste and the requirements of Statewide Order No. 29-B.

The wastes described above may be stored in production pits regulated by DNR if they are determined to meet the definition of RCRA exempt waste. LAC 43.XIX.301 defines production pits as "...either earthen or lined storage pits for collecting NOW (nonhazardous oilfield waste) sediment periodically cleaned from tanks and other producing facilities, for storage of produced water or other nonhazardous oilfield wastes produced from the operation of oil and gas facilities, or used in conjunction with hydrocarbon storage and solution mining operation." The benzene content of these production pits is not regulated by Statewide Order No. 29-B.

Chapter 3 of Statewide Order No. 29-B regulates pits constructed created by oil and gas producers to contain E&P waste. LAC 43.XIX.307.2 requires pits to be protective of surface waters by well maintained levees or walls. Drainage ditch construction is required when needed. LAC 43.XIX.307 also limits the top of the pit contents to remain within 2 feet of the top of the walls or levees (free board). Pit liner requirements are regulated in Sections 301.A.1.a and 307.E.3 (Emergency pits). Where applicable, the liner must consist of a natural layer of clay, a soil mixture layer of cement and clay-type material, a recompacted clay liner of existing clay or imported clay, a manufactured synthetic liner, or a combination liner consisting of two or more types of liners. All liners must exhibit hydraulic conductivity no greater that 1×10^{-7} cm/sec as regulated in Section 307.A.1.a and E.3 of Statewide Order No. 29-B.

In 1998, salt water (produced brine) and water based mud cuttings accounted for approximately 70% of all E&P waste generated. Reible and Valsaraj determined 10-30 % of the samples tested (iii) for waste types 01, 04, 05, and 11 all exceeded the toxicity characteristic leaching procedure concentration (TCLP) of 0.5mg/L, for benzene in soil. These waste types were 63.2 % of all the E&P waste generated in 1998 (Reible and Valsaraj, iv). TCLP benzene

concentrations in produced sands and solids were higher than the in excess of 33% of the samples. More E&P wastes exceeded the 0.5 mg/L benzene limiting standard than did not (Reible and Valsaraj (v)).

In more than 33% of waste types, 06, 07, 12, 13, and 14, the TCLP limiting standards were exceeded (Reible and Valsaraj, v). When commingled, wastes will therefore exceed the standards. Most of the waste types have a high probability of exceeding the TCLP limiting standards as seen in "TCLP Characterization of Exploration and Production Wastes in Louisiana". The Louisiana Department of Natural Resources funded the E&P waste study by Reible and Valaraj.

The goal of a December 2000 study and report by Pardue and Valsaraj, "Assessment of Air Emissions at the US Liquids Exploration and Production Land Treatment Facility", was to establish a baseline assessment of air emissions from E&P waste in commercial facilities (8). TO collect air samples, the LSU professors used a galvanized sheet metal structure to capture E&P waste air emissions in its chambers by creating headspace. (Pardue and Valsaraj, 8)

The emissions were tested to determine the effects to human health of workers and the surrounding areas from exposure to benzene, toluene, ethylbenzene, xylene (BTEX) and hydrogen sulfide. Higher emission levels were detected in areas where waste had just been spread. Low emissions were found in older treatment cells. BTEX levels that were measured ranged from 2 to 200 $mg/m^2/day$. Benzene fluxes at the Bateman Island and the Bourg facilities ranged from 0.19 kgs per day to 0.27 kgs per day respectively. Air concentrations did not exceed OSHA standards above the cell except for one set of flux measurements. (Pardue and Valsaraj, 8-9)

The same waste products disposed of in commercial land treatment cells are stored in production and reserve pits. The cells tested contained a top layer of water that reduces the

volatilization of benzene until mixing. These results are not typical of indoor air emissions but do establish a comparative example of benzene air concentrations. When in soil, benzene is kept at a steady state temperature with little or no change and is usually not influenced by water. Most of the waste tested had a propensity to exceed the TCLP limiting standard.

BENZENE CHEMISTRY AND TOXICOLOGY

Benzene is a colorless, highly flammable liquid that has a chemical formula of C_6H_6. It is an aromatic hydrocarbon with a molecular weight of 78.1 (Paustenbach, Bass, and Price, 177-8). The vapor pressure of benzene is 75 mm Hg causing it to be very volatile and had a Henry's law constant of 5.5×10^{-3} atm m^3/mole. The density of benzene (0.8737 g/mL at 25°) is less than that of water causing it to float. The solubility of benzene in water can be up to 1750 mg/L at 25°. The density allows the undissolved portion of benzene to float atop the water and easily volatilize into the air. (Paustenbach, Bass, and Price, 177-8).

Occupational Safety Health Administration (OSHA) Benzene Standards ("Benzene Toxicity Standards and Regulations, ATSDR)

- Permissible Exposure Limit (PEL) – 1 ppm per 8-hour Time Weight Average.
- Short-term Exposure Limit (STEL) – 5 ppm for any 15 minute period.

National Institute for Occupational Safety and Health Benzene Standards (NIOSH) ("Benzene Toxicity Standards and Regulations, ATSDR)

- Time Weighted Average (TWA) – 0.1 ppm per 10-hour Time Weight Average.
- Short-term Exposure Limit (STEL) – 1.0 ppm for 15-minute ceiling limit.

Short-term exposure symptoms to benzene are shortness of breath, irritability, and euphoria. Symptoms may also include irritation to the eyes, nose and respiratory tract. Headaches, dizziness, and nausea may also be experienced. Convulsions and the loss of consciousness are experienced in severe acute exposure cases. These symptoms are all experienced below the odor threshold. A person will not be aware of their exposure to benzene vapors until symptoms are experienced. (US EPA, Technology Transfer Network Air Toxic Website)

Chronic exposure is accumulated exposure over a long period of time. Low levels of benzene remain a concern for chronic exposure since benzene is a known carcinogen. The symptoms of chronic exposure are blood disorders such as anemia and leukemia. One of the dangers of chronic exposure is that symptoms of disease are not necessarily present until years later. The estimated benzene risk for lifetime leukemia deaths from exposure to 1 ppm of benzene in air is estimated to be approximately 5 in 1000 (ATSDR, "Toxilogical Profile for Benzene").

The three pathways for concern from benzene are ingestion, absorption, and inhalation. For this study we will focus on the latter, which is the most hazardous. Dermal absorption is not as hazardous because of benzene's extremely volatile nature. Several studies have shown that approximately 50% of benzene is absorbed in the respiratory system (US EPA, Toxicological Review of Benzene, 26). Approximately 30% of the benzene inhaled is not excreted by exhaling, but remains for adsorption by the alveoli system (US EPA, Toxicological Review of Benzene, 26). Low levels of benzene inhalation are excreted through urine in the form of sulfates system (US EPA, Toxicological Review of Benzene, 26). Women will retain more absorbed benzene than men will. Benzene is also transferable to the placenta via blood and has been detected in umbilical cord blood. This is important when studying indoor air benzene concentrations because mothers with small children are more likely to spend time in the home.

When inhaled, benzene passes through the respiratory system and is absorbed by the blood that passes through the lungs. Via the blood stream, the absorbed benzene passes through the body. Benzene is distributed to the fat stores of the body, bone marrow, mammary glands, nasal and oral cavities, and the liver system (US EPA, Toxicological Review of Benzene, 26). In extreme cases of benzene inhalation, the brain, kidneys, stomach and bile have all tested positive for benzene concentrations. Benzene, when metabolized in the liver, breaks down into phenol,

catechol, and hydroquinone system (US EPA, Toxicological Review of Benzene, 27) Phenol and hydroquinone are toxic metabolites that target the bone marrow. Benzene's toxicity is influenced by the combination of the metabolites. The stem and progenitor cells in bone marrow are affected as well as the body's ability to produce white blood cells, which can be fatal. Measuring the levels of sulfates and phenol in the urine is a good way to monitor benzene exposure system. (US EPA, Toxicological Review of Benzene, 27)

METHODOLOGY

Risk in this thesis is defined as the probability of experiencing negative long-term health effects stemming from exposure to a chemical at a specific location. The location discussed is residential and light commercial property developments on abandoned oil and gas production sites. The first step is to calculate the risk-based concentration of benzene in air using the equation, (Thomas, 57)

$$C_a = \frac{TR \times BW \times AT_c \times 365}{ED \times EF \times IR_a \times SF_i}$$

Where:

C_a	= Risk-based concentration of benzene in air (mg/m^3)	0.0003
TR	= Target risk	0.000006
BW	= Body weight (average weight of adults and children)	70
AT_c	= Averaging time for carcinogens (years)	70
365	= Conversion factor (days/year)	365
ED	= Exposure duration (years)	30
EF	= Exposure frequency (days/year)	350
IR_a	= Inhalation rate (m^3 of air/day)	20
SF_i	= Slope factor for inhalation [risk per (mg of benzene/kg body wt-day)]	0.029 (LDEQ RECAP App. H)

All values taken from Johnson and Ettinger except for slope factor.

$$C_a = \frac{.000006 \times 70 \times 70 \times 365}{30 \times 350 \times 20 \times 0.029}$$

$$C_a = \frac{1.7885}{6090}$$

$$C_a = 0.0003$$

The risk-based concentration of benzene in air as calculated by the equation above is 0.0003 mg/m^3.

The calculated concentration of benzene will be the baseline for indoor air in a residential setting. Any calculated value from the Johnson and Ettinger Model below the risk-based concentration will be considered protective of human health. The Johnson and Ettinger Model (1991) for Subsurface Vapor Intrusion into Buildings (Waste and Cleanup Risk Assessment) from soil will be used to calculate the estimated air concentration in a home built on a known concentration of benzene. Groundwater will not be modeled because groundwater has strict existing monitoring standards. The Johnson and Ettinger Model chose the chemicals to be evaluated based on the toxicity of the chemical. The criteria for toxicity are having cancer risk greater than $1x10^{-6}$ and a Henry's law constant of $1x10^{-5}$ atm-m^3/mole or greater. The toxicity values used by the Johnson and Ettinger Model were taken from EPA's Integrated Risk Information System. Many assumptions were made such as contaminant distribution and occurrence, subsurface characteristics, transport mechanisms, and building construction (Waste and Cleanup Risk Assessment).

The Johnson and Ettinger Model attempts to calculate the soil vapors from diffusion and convection methods. The one-dimensional model relates the soil vapor concentration of the contaminant to the indoor air concentrations. Attenuation is not accounted for in this model. All soil characteristics and contamination are assumed to be homogenous throughout the soil zones. All contaminants that are below the soil saturation limit can be modeled, but if the contaminants are above the soil saturation limit they will be set at that standard. The soil saturation limit for benzene is $9.12 \times 10^{+2}$ mg/kg. (Environmental Quality Management, Inc, 3)

There are many assumptions and limits to the model. These assumptions could alter actual situations. The first assumption is that there are no other sources of the contaminant in the

structure. The contaminant source will be at equilibrium and the diffusion will be insignificant through soil mixtures. Convection will be most prominent at the foundation and Darcy's law will describe the vapor flow. All convection will be in a steady state, and uniform through the porous medium and the foundation. All vapors present are assumed to enter the structure through the cracks and openings between the walls and the foundation. Absorption to the organic content will be calculated using sample data. (Environmental Quality Management, Inc 67-9)

To run the model, real data must be supplied or the default settings can be used. The chemical to be modeled was selected by its CAS number, 7-41-32 (benzene), from a list provided in the Johnson and Ettinger model. The soil concentration of benzene was determined by the user and was assumed to be an average across a homogenous zone. The concentrations selected are .05 mg/kg, 113 mg/kg, 3198 mg/kg, and 5,900 mg/kg. The maximum permissible input value for benzene concentrations is 912 mg/kg due to the model setting at the soil solubility point for benzene and will be used if the input values are higher. Based on the results, other concentration values may be selected (if needed) to calculate benzene levels lower than the calculated benzene air concentration standards. The benzene TCLP of 0.5 mg/kg concentration used in the E&P TCLP report by Reible and Valsaraj was lowered by a factor of ten and used for the thesis because numerous waste types exceeded the 0.5 mg/kg TCLP standard. The author decided to use a more conservative concentration. The higher concentrations were chosen because Section 507.3 of Statewide Order No. 29-B states that land treatment facilities are not permitted to receive waste with concentrations above 113 mg/kg and 3198 mg/kg for waste type 06 and waste type 12 respectively. According to McMillen, Sara J. et al, 5900 mg/kg was the maximum concentration of benzene recorded from 69 unweathered crude oils tested around the world (158). For this model, the thickness of the contaminated soil zone is 2 ft because samples are usually taken in 2 ft increments when sampled per LDEQ RECAP sampling procedures.

The next input is the average soil temperature. Data from the Louisiana Agriclimatic Information provided by the Louisiana State University Agriculture Center was used. Daily maximum and minimum soil temperatures measured at 10 cm below the ground surface was averaged. The soil temperature data used in the model was collected from October 17, 2006 to October 16, 2007 to represent the most current conditions. The equation below was used to determine the average soil temperature.

$$AvgSoilTemp = \left(\frac{MaxTemp + MinTemp}{365} \right) / 2$$

$$AvgSoilTemp = \left(\frac{28433 + 24727}{365} \right) / 2$$

$$AvgSoilTemp = 72.82^{\circ}\text{F}$$

The average temperature for October 17, 2006 through October 16, 2007 was 72.82° Fahrenheit.

The next entry into the model is the slab depth below grade. Johnson and Ettinger made the assumption that 15 cm of the slab was below grade (Environmental Quality Management, Inc, 47). The depth to the top of the contaminated soil from the bottom of the slab is a user input value assumed to be at 3 ft (91.44 cm). This depth was made assuming the contamination bottom depth was at 5 feet below ground surface due to pit closure regulations as stated in Section 313.E.5 of Statewide Order No. 29-B for burying or trenching.

The Johnson and Ettinger model allows up to three different soil strata. The author used soil data from three soil surveys in Acadia Parish 1996 (26), Lafourche Parish 1984 (102), and Ouachita Parish 1974 (72). One core sample per survey and the three most prevalent soil types for that core are used. Silt loam, silty clay loam, and silty clay for Acadia Parish, silt loam, sandy loam, and clay for Lafourche Parish, and sandy loam, loam, and sandy clay loam for Ouachita Parish were input into the model. The three different regions were selected to classify

three soil types in oil producing areas of Louisiana (Ouachita Parish in the north, Lafourche Parish in the southeast coastal zone, and Acadia Parish in the southwest). Soil types are consistent with the United States Department of Agriculture Soil Conservation Service (USDA SCS) (Environmental Quality Management, Inc, 50).

ABBREVIATION	SCS SOIL TYPE
C	Clay
CL	Clay loam
L	Loam
LS	Loamy sand
S	Sand
SC	Sandy Clay
SCL	Sandy clay loam
SI	Silt
SIC	Silty clay
SICL	Silty clay loam
SIL	Silty loam
SL	Sandy loam

The soil vapor permeability is calculated by using the default settings for the SCS soils (see Table 1). The permeability ranges from 1.0×10^{-6} in medium sands to 1.0×10^{-9} for clayey silts (see Table 1). The user will input the vadose zone soil, which is the soil zone directly above the water table, and must be the thickest zone input. (Environmental Quality Management, Inc, 51)

Table 1. Range of Values For Selected Input Parameters		
Input parameter	Practical range of values	Default values
Soil water-filled porosity	0.04 – 0.33 cm^3/cm^3	Soil dependent
Soil vapor permeability	10^{-6} – 10^{-12} cm^2	10^{-8} cm^2
Soil-building pressure differential	0 – 20 Pa[3]	4 Pa
Media initial concentration	User-defined	NA
Depth to bottom of soil contamination	User-defined	NA
Depth to top of concentration	User-defined	NA
Floor-wall seam gap	0.05 – 1.0 cm	0.1 cm
Soil organic carbon fraction	User-defined	NA
Indoor air exchange rate	0.18 – 1.26 H^{-1}	0.25 H^{-1}
Soil total porosity	0.34 – 0.53 cm^3/cm^3	0.43 cm^3/cm^3
Soil dry bulk density	1.25 – 1.75 g/cm^3	1.5 g/cm^3
Note: Information from User's Guide for Evaluating Subsurface Vapor Intrusion Into Buildings, February 22, 2004, Table 7, Page 34		

The soil dry bulk density and the soil total porosity will be represented by the default measurements given by SCS (see Table 1 and 2). The soil water-filled porosity will be calculated in the same manner. The above information was not available from the soil surveys reviewed. The data gathered did not represent long-term trends of the soil. (Environmental Quality Management, Inc, 51-3)

Table 2. Centroid Compositioons, Mean Particle Diameters and Dry Bulk Density of the 12 SCS Soil Textural Classifications					
Textural Class	Percent clay	Percent silt	Percent sand	Arithmetic mean particle diameter, cm	Dry bulk density, g/cm^3
Clay	64.83	16.55	18.62	0.0092	1.43
Clay loam	33.50	34.00	32.50	0.0160	1.48
Loam	18.83	41.01	40.16	0.0200	1.59
Loamy sand	6.25	11.25	82.50	0.0400	1.62
Silt	6.00	87.00	7.00	0.0046	1.35
Silty loam	12.57	65.69	21.74	0.0110	1.49
Table continued on next page.					

Silty clay	46.67	46.67	6.66	0.0039	1.38
Silty clay loam	33.50	56.50	10.00	0.0056	1.63
Sand	3.33	5.00	91.67	0.0440	1.66
Sandy clay	41.67	6.67	51.66	0.0250	1.63
Sandy clay loam	26.73	12.56	60.71	0.0290	1.63
Sandy loam	10.81	27.22	61.97	0.0300	1.62
Note: Information from User's Guide for Evaluating Subsurface Vapor Intrusion Into Buildings, February 22, 2004, Table 4, Page 19					

The average organic content was taken from the first 5 feet of all core samples taken from each Parish (see Table 3). The fraction organic carbon is found by dividing each organic content value by 174 and adding them to get the total fraction organic carbon as specified in LDEQ RECAP.

Table 3. Fraction Organic Carbon Calculations		
Acadia Parish	Organic Content	Fraction Organic Carbon
0-4 in	1.47 / 174	0.008
4-8 in	0.68 / 174	0.004
8-16 in	0.64 / 174	0.004
16-29 in	0.85 / 174	0.005
29-48 in	0.23 / 174	0.001
48-60 in	0.07 / 174	0.0004
		TOTAL = 0.0224
Lafourche Parish		
0-22 in	2.0 / 174	0.011
0-65 in	0.5 / 174	0.003
		TOTAL = 0.014
Ouachita Parish		
0-1 in	1.61 / 174	0.009
1-6 in	0.42 / 174	0.002
Table continued on next page.		

6-14 in	0.25 / 174	0.001
14-19 in	0.18 / 174	0.001
19-26 in	0.14 / 174	0.0008
26-42 in	0.07 / 174	0.0004
42-53 in	0.03 / 174	0.0002
53-63 in	0.03 / 174	0.0002
		TOTAL = 0.0146

The approximate floor slab thickness is assumed to be 12 in (30.48 cm). All slabs are assumed to be in constant contact with the soil directly under and the slabs which are impermeable. The soil-building pressure differential is adjusted according to the stack effects due to heated air, wind effects, and unbalanced ventilation that causes a negative pressure in the home. The negative pressure encourages an upward flow of the soil vapors through the imperfections in the slab wall junction. (Environmental Quality Management, Inc, 53-4)

The floor slab length and width will be set at a default of 1000 cm for each. The height of the space in the home is set at 9 feet (2.44 m). The heating, ventilation, and air conditioning unit will influence the air mixing of the space. Floor heaters and window units would lessen the mixing heights because of the lack of circulation. (Environmental Quality Management, Inc, 54)

The floor-wall seam crack width is the gap between the wall and the floor. This is considered to be the route of entry for soil vapors. The default value of 0.1 cm will be used for calculation. The assumption of a 1000 cm by 1000 cm structure will equate to a 900 cm^2 gap area. (Environmental Quality Management, Inc, x, 54-5) Piping into the structure is not considered in the calculation of the exposure route area.

The indoor air exchange rate will use the default setting of 0.25/h and is calculated using an area of 1000 cm^2. This value is representative of the lower values as stated by Johnson and Ettinger. (Environmental Quality Management, Inc, x, 56)

The average time for cancer development will be set at 70 years and the exposure duration will be set at 350 days/yr. The default setting for the target risk of carcinogens will be set at 1 x 10^{-6}. (Environmental Quality Management, Inc, 56) All user defined inputs for this model are shown in Table. 4.

Table 4. User Defined Input Values For the Johnson and Ettinger Model	
Risk-based concentration of benzene in air (mg/m^3)[1]	0.0003
Soil benzene concentrations (mg/kg)	0.05, 113, 912
Average Soil Temp (C^o)[2]	22.68
Slab depth below grade (cm)	15
Depth to the top of the contaminated soil from the bottom of the slab (cm)	91.44 (3 ft)
Fraction organic carbon	
Acadia Parish Soil	0.0224
Lafourche Parish Soil	0.0140
Ouachita Parish Soil	0.0146

CALCULATIONS

The risk-based concentration was calculated using Thomas' equation from the Phase III Report on E&P waste. The calculated risk-based value of 0.0003 mg/m^3 will be used as the standard for risk to human health from indoor air benzene vapor calculations in the Johnson and Ettinger model (see Table 5). Values above the calculated risk-based concentration are assumed harmful to human health. The calculations can be viewed in Appendix B through Appendix J pp. 45-77.

Acadia Parish Calculations

Soil concentration values of 0.05 mg/kg, 113 mg/kg, and 912 mg/kg were used to determine the indoor air concentration of benzene. The indoor air concentration of benzene from soil exhibiting a concentration of 0.05 mg/kg, as calculated by the Johnson and Ettinger model, is 0.0002 mg/m^3 and protective of human health. The indoor air concentration of benzene with a soil concentration of 113 mg/kg, as calculated by the Johnson and Ettinger model, is **0.395 mg/m^3**. The indoor air concentration of benzene from a soil concentration of 912 mg/kg, as calculated by the Johnson and Ettinger model, is **3.19 mg/m^3**. Benzene concentrations in soil of 113 mg/kg and 912 mg/kg exceed the risk-based standard of 0.0003 mg/m^3 (see Table 5).

Lafourche Parish Calculations

Soil concentration values of 0.05 mg/kg, 113 mg/kg, and 912 mg/kg were used to determine the indoor air concentration of benzene. The indoor air concentration of benzene from soil exhibiting a concentration of 0.05 mg/kg, as calculated by the Johnson and Ettinger model, is 0.0002 mg/m^3 and protective of human health. The indoor air concentration of benzene from a soil concentration of 113 mg/kg, as calculated by the Johnson and Ettinger model, is **0.467 mg/m^3**. The indoor air concentration of benzene from a soil concentration of 912 mg/kg,

as calculated by the Johnson and Ettinger model, is **3.77 mg/m^3**. Benzene concentrations in soil of 113 mg/kg and 912 mg/kg exceed the risk-based standard of 0.0003 mg/m^3 (see Table 5).

Ouachita Parish Calculations

Soil concentration values of 0.05 mg/kg, 113 mg/kg, and 912 mg/kg were used to determine the indoor air concentration of benzene. The indoor air concentration of benzene exhibiting a soil concentration of 0.05 mg/kg, as calculated by the Johnson and Ettinger model, is 0.0002 mg/m^3 and protective of human health. The indoor air concentration of benzene from a soil concentration of 113 mg/kg, as calculated by the Johnson and Ettinger model, is **0.410 mg/m^3**. The indoor air concentration of benzene from a soil concentration of 912 mg/kg, as calculated by the Johnson and Ettinger model, is **3.31 mg/m^3**. Benzene concentrations in soil of 113 mg/kg and 912 mg/kg exceed the risk-based standard of 0.0003 mg/m^3 (see Table 5).

Table 5. Johnson and Ettinger Results For Subsurface Vapor Intrusion From Exploration and Production Waste

Acadia Parish Soil Results	
Soil concentration (mg/kg)	Indoor air concentrations (mg/m^3)
0.05	0.0002
113	0.395
912	3.19
Lafourche Parish Soil Results	
Soil concentration (mg/kg)	Indoor air concentrations (mg/m^3)
0.05	0.0002
113	0.467
912	3.77
Ouachita Parish Soil Results	Indoor air concentrations (mg/m^3)
Soil concentration (mg/kg)	0.0002
0.05	0.410
113	3.31
912	

CONCLUSIONS AND RECOMMENDATIONS

Thomas was first to discuss benzene in E&P waste in November of 2001. The report was conducted based on complaints of sicknesses experienced by locals living near the US Liquids facilities. It was discovered that the concentration of benzene in the air was negligible and peaked in relation to the activities on the land treatment cell. Harm was not found by the ATSDR standards. Disturbances such as the loading of E&P waste into the cell and the mixing of the cell allowed the constituents to volatilize. These fluxes were short lived with cell aging the emissions decreased significantly. The report did not have a direct connection with onsite production pits but it did represent the volatile characteristics of benzene.

The calculations from the Johnson and Ettinger model for Acadia Parish soils returned the lowest concentrations for indoor air. These results are consistent with the soil types exhibited and the higher organic carbon present. Silt loam, silty clay loam and silty clay are fine grain soils which inhibit upward migration of benzene vapors. Benzene also attaches to the organic content of the soil, reducing migration further.

The results from the Lafourche Parish soil calculations were also consistent with the soil types and the organic carbon content. The soil grains for silt loam, sandy loam, and clay allows for higher air permeability rates than the Acadia soils because of the increased sand content. The presence of larger sand grains and the lower organic content allow for increased vapor intrusion.

Ouachita Parish soils allowed the highest intrusive concentrations of benzene vapors into the structure located above. The soil content consisted of sandy loam, loam, and sandy clay loam, which allow higher permeability rates due to a larger volume of sand grains. The organic content was also low, reducing the amount of benzene absorbed to the organic carbon.

The purpose of this study was to determine the amount of subsurface vapor intrusion from E&P waste. Benzene was chosen due to its high volatility, high toxicity, and the lack of regulation by DNR for pit closures. The results of this study suggest that physical investigations of indoor vapor intrusion of benzene would be warranted prior to residential developments on abandoned oil and gas production sites.

The benzene concentrations tested in this thesis were based on worse case scenarios from known benzene concentrations in E&P waste that is remediated at commercial disposal facilities. Already existing benzene concentrations for TCLP regulations for land treatment cells from Pardue and Valsaraj were also used. In cases where soil concentrations at the benzene solubility levels in soil (912 mg/kg) and benzene soil concentrations of 113 mg/kg were modeled, indoor air concentrations exceed OSHA standards of the PEL at 1 ppm per 8-hour work day, the NIOSH TWA at 0.1 ppm per 10-hours and the STEL value of 1.0 ppm for a 15-minute ceiling limit. The indoor air concentrations for benzene also exceeded the risk-based calculations of 0.0003 mg/kg. Benzene with soil concentrations of 0.05 mg/kg did not exceed the OSHA, NIOSH, or calculated risk-based calculations. The chronic exposure to calculated concentrations of benzene in indoor air would have a greater effect on residents, especially women and children, who generally are home for longer durations.

Due to these results, benzene should be tested either during closure of a pit or before residential and light commercial facilities are developed. Adding a benzene soil screening standard can be achieved by adding an amendment to Statewide Order No. 29-B. The closure of oilfield pits is regulated by Section 313 of Statewide Order No. 29-B and currently testing for benzene is not requiered. Metals, pH, oil and grease, and salts are tested and must past limiting standards before closure of the pit can be completed. The screening standard proposed for benzene in soil is 0.05 mg/kg based on results calculated by the Johnson and Ettinger model

(DEQ benzene screening levels of soil protective of indoor air for nonindustrial use is set at 1 ppm). All results of benzene air concentrations were found to be under the MPC at the suggested screening standard.

If benzene concentrations in soil exceed the screening standard of 0.05 mg/kg, further soil testing should be conducted prior to closure to establish a boundary of the benzene contamination. Soil testing should be conducted under best practiced procedures approved by DNR. Samples should be collected by using direct push technology to take core samples continuously every two feet until groundwater is reached. Groundwater is chosen as the bottom depth of the borehole because pits are currently protective of groundwater. Upon sampling completion, the boring must be grouted to the ground surface with a bentonite cement mixture to protect against downward migration of benzene. All samples must be analyzed by DNR approved laboratories following techniques currently approved in DNR laboratory procedure manual.

The second closure option would be to conduct closure practices under the status quo. If preferred, the rule could be amended to require sampling and testing of the former pit area for benzene in the soil prior to land development for residential or light commercial purposes. The responsible party should be required to state in a conveyance notice that further testing of benzene is necessary prior to land development. Liability will remain with the responsible party regardless of any sale. All sampling procedures will be conducted as stated above to determine if remediation of the property is necessary prior to development. Remediation procedures will be conducted if the soil-screening standard of 0.05 mg/kg is exceeded. DNR and the responsible party would agree upon the remediation techniques. Soil samples of the remediated soil must confirm that the benzene concentration in soil is below the established screening standard and protective of human health.

Should oil and gas operators be required to determine benzene levels prior to pit closure, the most cost effective and prudent sampling and testing should be used. Any new standards set by Statewide Order No. 29-B should ensure the land is fit for residential and light commercial development. Soil with a benzene concentration below 0.05 mg/kg would be assumed protective of indoor air. Testing the soil for benzene prior to land development would show diligence by the responsible party. If legal action is taken against the responsible party for further remediation of the soil after a development is established, liability would be limited because benzene remediation below the required soil-screening standards prior to development had been approved by DNR. If soil were determined not to be suitable for development, the developer could proceed with available DNR administrative procedures to provide the responsible party the opportunity to remediate the property further.

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APPENDIX A

STATEWIDE ORDER 29-B EXERPTS

STATEWIDE ORDER NO. 29 B

(Excerpts from LAC 43: XIX Chapter 3 and 5)

Section 301. Definitions

Contamination – the introduction of substances or contaminants into a groundwater aquifer, a USDW or soil in such quantities as to render them unusable for their intended purposes.

Exempt Pits – compressor station pits, natural gas processing plant pits, emergency pits, and salt dome cavern pits, emergency pits, and salt dome cavern pits located in the coastal area.

Hydrocarbon Storage Brine – well water, potable water, rainwater, or brine (partially saturated) used as a displacing fluid in hydrocarbon starage well operations.

Manufactured Liner – any man-made synthetic material of sufficient size and qualities to sustain a hydraulic conductivity no greater than 1 $x10^{-7}$ cm/sec after installation and which is sufficiently reinforced to withstand normal wear and tear associated with the installation and pit use without damage to the liner or adverse affect on the quality thereof. For purposes of this Chapter and Chapter 5, a manufactured liner used in pit construction must meet or exceed the following standards.

PARAMETER OR TEST STANDARD	
Thickness (average)	> 10 mm (0.01 in)
Breaking Strength (Grab Method)	90 lbs
Bursting Strength	140 psi
Tearing Strength	25 lbs
Seam Strength	50 lbs

Nonhazardous Oilfield Waste – as defined in Section 501.

NOW – nonhazardous oilfield waste.

Onsite – for purposes of this Section, on the same lease or contiguous property owned by the lessor, or within the confines of a drilling unit established for a specific well or group of wells.

Pit – for purposes of this Chapter, a natural topographic depression or man-made excavation used to hold produced water or other nonhazardous oilfield waste, hydrocarbon storage brine, or mining water. The term does not include lined sumps less than 660 gallons or containment dikes, ring levees or firewalls constructed around oil and gas facilities.

Produced Water – liquids and suspended particulate matter that is obtained by processing fluids brought to the surface in conjunction with the recovery of oil and gas from underground geologic formations, with underground storage of hydrocarbons, or with solution mining for brine.

Production Pits – either earthen or lined storage pits for collecting NOW sediment periodically cleaned from tanks and other producing facilities, for storage of produced water or other nonhazardous oilfield wastes produced from the operation of oil gas facilities, or used in conjunction with hydrocarbon storage and solution mining operation.

Reserve Pits – Temporary earthen pits used to store only those materials used or generated in drilling and workover operations.

Section 307. Pit Classification, Standards, and Operational Requirements

A.1.a. A liner along the bottom and sides of pits which has the equivalent of 3 continuous feet of recompacted or natural clay having a hydraulic conductivity no greater than. Such liners include, but are not liited to the following:

i. Natural Liner – Natural clay having a hydraulic conductivity meeting the requirements of sec. 307.A.1.a above;

ii. Soil Mixture Liner – soil mixed with cement, clay-type, and/or other additives to produce a barrier which meets the hydraulic conductivity requirements of sec. 307.A.1.a above;

iii. Recompacted Clay Liner – in situ or imported clay soils which are compacted or restructured to meet the hydraulic conductivity requirements of sec. 307.A.1.a above;

iv. Manufactured Liner – synthetic material that meets the definition I Sec. 301 and is equivalent or exceeds the hydraulic conductivity requirements of Sec 307.A.1.a above. Pits constructed with a manufactured liner must have side slopes of 3:1 and the liner at the top of the pit must be buried in a 1-inch wide and 1-inch deep trench. A sufficient excess of liner material shall be placed into the pit to prevent tearing when filled with NOW;

v. Combination Liner – a combination of two or more types of liners described in this Section which meets the hydraulic conductivity requirements of sec. A.1.a above;

E. Emergency Pits

1. Groundwater aquifer and USDW protection for emergency pits shall be evaluated on a case-by-case basis. Operators who intended to utilize existing or new emergency pits without liners must demonstrate by written application to the Office of Conservation that groundwater aquifer and USDW contamination will not occur; otherwise, emergency pits shall be lined. Applications to demonstrate unlined pits will not contaminate groundwater aquifers and USDWs shall at a minimum address the following:

a. Emergency Incident Rate – Operator shall estimated the number of times a pit will be utilized each year. A detailed discussion of the facility operation and reasons for the emergency incident rate must be addressed.

b. Soil Properties – Operator shall describe and evaluate soil properties onsite. Soil hydraulic conductivity and physical properties must be addressed to asess potential groundwater aquifer and USDW impacts.

c. Groundwater Aquifer Evaluation – water quality, groundwater aquifer, and USDW depth shall be evaluated.

d. Produced Water Composition (total dissolved solids and oil and grease) – must be determined to assess potential impacts on the site.

2. All emergency pits required to be lined must conform to hydraulic conductivity requirements in sec. 307.A.1.

3. No produced water or any other NOW shall be intentionally placed in any emergency pit not meeting the hydraulic conductivity requirements (1x10-7 cm/sec for 3 continuous feet of clay) except in the case of an emergency incident. In emergency situations, notice must be given within 24 hours after the discovery of the incident. Produced water and any other NOW must be removed from the pit within seven days following the termination of the emergency situation.

Sec. 311. Pit Closure

A. Pits must be closed properly to assure protection of soil, surface water, groundwater aquifers and USDWs. Operators may close pits utilizing onsite land treatment, burial, solidification or other techniques approved by the Office of Conservation only if done so in compliance with Sec. 313 and Sec. 315. Otherwise, all NOW must be manifested according to Sec. 511 and transported offsite to a permitted commercial facility.

C. For evaluation purposes prior to closure of any pit and for all closure and onsite and offsite disposal techniques, excluding subsurface infection of reserve pit fluids, nonhazardous oilfield waste (pit contents) must be analyzed for the following parameters:

1. PH;

2. total metals (ppm) for; arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, zinc,

3. Oil and Grease (percent dry weight);

4. Soluble salts and cationic distributions:

    a. electrical conductivity – EC in mhos/cm(millimhos);
    b. sodium adsorption ratio – SAR;
    c. exchangeable sodium percentage – ESP (percent); and
    d. cation exchange capacity – CEC (milliequivalents/100 gm soil).

5. Radioisotopes if such pit is located in the coastal area and is closed after October 20, 1990.

Section 313. Pit Closure Techniques and Onsite Disposal of NOW

C. For all pit closure techniques in this Subsection, except for solidification, waste/soil mixtures must not exceed the following criteria

1. range of pH: 6-9;

2. total metals content (ppm)

Parameter	**Limitation**
Arsenic	10
Barium	
Submerged Wetland Area	20,000
Elevated Wetland Area	20,000
Upland Area	40,000
Cadmium	10
Chromium	500
Lead	500
Mercury	10
Selenium	10
Silver	200
Zinc	500

D. Land Treatment. Pits containing NOW may be closed onsite by mixing wastes with the soil from pit levees or walls and adjacent areas provided waste/soil mixtures at completion of closure operations do not exceed the following criteria, as applicable unless the operator can show that higher limits for ED, SAR, and ESP can be justified for future land use or that background analyses indicate that native soil conditions exceed the criteria

1. ...if the oil and grease content of the waste/soil mixture after closure is < 1 percent (dry weight)

E. Burial or Trenching. Pits containing NOW may be closed by mizing the wate with soil and burying the mixture onsite, provided the material to be buried meets the following criteria:

4. oil and grease content: < 3 percent by weight;

5. top of buried misture must be at least 5 feet below ground level and then covered with 5 feet of native soil;

6. bottom of burial cell must be at least 5 feet above the seasonal high water table.

F. Solidification. Pits containing NOW may be closed by solidifying wastes and burying it onsite provided the material to be buried meets the following criteria:

2. leachate testing for oil and grease: <10.0 mg/l…

4. top of buried mixture must be at least 5 feet below ground level and covered with 5 feet of native soil;

5. bottom of burial cell must be at least 5 feet above the seasonal high water table;

LAC 43:XIX. Chapter 5

Section 501. Definitions

Commercial Facility – a legally permitted E&P Waste storage, treatment and/or disposal facility which receives, treats, reclaims, stores, and/or disposes of E&P Waste for a fee or other considerations. For purposes of this definition, DEQ permitted faciities, as defined by LAC 33;V and VII, which are authorized to receive E&P Waste, are not covered by this definition. However, such facilities must comply with the reporting requirements of Sec. 545.K herein if E&P Waste is accepted.

Drilling Waste – oil-base and water-base drilling mud or other drilling fluids and cuttings generated during the drilling of wells. These wastes are a subset of E&P Waste

Exploration and Production Waste (E&P Waste) – drilling wastes, salt water, and other wastes associated with the exploration, development, or production of crude oil or natural gas wells and which is not regulated by the provisions of, and, therefore, exempt form the Louisiana Hazardous Waste Regulations and the Federal Resource Conservation and Recovery Act, as amended. E&P wastes include, but are not limited to the following:

WASTE TYPE	E&P WASTE DESCRIPTION
01	Salt water (produced brine or produced water), except for salt water whose intended and actual use is in drilling, workover or completion fluids or in enhanced mineral recovery operations, process fluids generated by approved salvage oil operators who only receive oil (BS&W) from oil and gas leases, and nonhazardous natural gas plant processing waste fluid which is or may be commingled with produced formation water
02	Oil-base drilling wastes (mud, fluids and cuttings).
03	Water-base drilling wastes (mud, fluids and cuttings).
04	Completion, workover and stimulation fluids.
05	Production pit sludges.
06	Storage tank sludge from production operations, onsite and commercial saltwater disposal facilities, DNR permitted salvage oil facilities (that only receive waste oil [BS, & W] from oil and gas leases), and sludges generated by service company and commercial

	facility or transfer station wash water systems.
07	Produced oily sands and solids.
08	Produced formation fresh water.
09	Rainwater from firewalls, ring levees and pits at drilling and production facilities.
10	Washout water and residual solids generated from the cleaning of containers that transport E&P Waste and are not contaminated by hazardous waste or material; washout water and solids (E&P Waste Type 10) is or may be generated at a commercial facility or transfer station by the cleaning of a container holding a residual amount (no more than one barrel) of E&P Waste.
11	Washout pit water and residual solids from oilfield related carriers and service companies that are not permitted to haul hazardous waste or material.
12	Nonhazardous Natural gas plant processing waste solids.
13	(Reserved).
14	Pipeline test water which does not meet discharge limitations established by the appropriate state agency, or pipeline pigging waste, i.e., waste fluids/solids generated from the cleaning of a pipeline.
15	E&P Wastes that are transported from permitted commercial facilities and transfer stations to permitted commercial treatment and disposal facilities, except those E&P Wastes defined as Waste Types 01 and 06.
16	Crude oil spill clean-up waste.
50	Salvageable hydrocarbons bound for permitted salvage oil operators.
99	Other E&P Waste not described above (shipment to a commercial facility or transfer station must be preapproved prior to transport).

Land Treatment – a dynamic process involving the controlled application of E&P Waste onto or into the aerobic surface soil horizon in open cells by a commercial land treatment facility, accompanied by continued monitoring and management, to alter the physical, chemical, and biological state of the E&P Waste. Site, soil, climate, and biological activity interact as a system to degrade and immobilize E&P Waste constituents thereby rendering the area suitable for the support of vegetative growth and providing for beneficial future land use or to meet the reuse criteria of Section 565.

MPC – maximum permissible concentration

Oil-Based Drilling Muds – any oil-based fluid composed of a water in oil (hydrocarbon or synthetic) emulsion, organophillic clays, drilled solids and additives for down-hole rheology and stability such as fluid loss control materials, thinners, weighting agents, etc.

Treatment – as applied to Type A Facilities (defined herein), excluding Transfer Stations, treatment shall be defined as any method, technique, or process capable of changing the physical and/or chemical characterization or composition of E&P Waste so as to reclaim salvageable hydrocarbons, process reusable material, reduce waste volume (volume reduction), neutralize

waste, reduce Section 549 criteria concentration(s) or otherwise render the waste more suitable for handling, storage, transportation, and/or disposal.

Treatment Phase – the period of time during which E&P Waste in a land treatment cell is physically manipulated and/or chemically altered (through the addition of chemical amendments, etc.) to bring the cell into compliance with the testing criteria or reuse criteria of LAC 43:XIX.549 and 565.

Type A Facility – a commercial E&P Waste disposal facility within the state that utilizes technologies appropriate for the receipt, storage, treatment, or disposal of E&P Waste solids and fluids (liquids) for a fee or other consideration.

Section 503. General Requirements for Generators of E&P Waste

A.3. At a minimum, E&P Waste should be tested for the following constituents : pH, TPH, EC, TCLP benzene, SAR, ESP.....

F.1. Generators of Waste Type 06 are hereby made aware that commercial lansd treatment facilities must manage such wste in compliance with the location criteria of Section 507.A.3 and the maximum permissible concentration (MPC) requirements of Section 549.C.7.c and d for total benzene.

2. Waste Types 12 is not required to be tested for benzene if disposed at commercial facilities that utilize treatment options other than land treatment (see section 547)

3. Prior to shipment and disposal at commercial land treatment facilities, natural gas plant processing waste solids (gas plant waste – Waste Type 12) must be analyzed for the chemical compound benzene (C_6H_6).

4. Subject to the requirements of Section 507.A3 and Section 549.C.7.a, Waste Type 12 may be disposed at any commercial land treatment facility if test data indicates the waste is less than or equal to the MPC of 3198 mg/kg total benzene.

5.b. treat the waste (on-site) to a concentration of total benzene equal to or below 3198 mg/kg prior to off-site shipment to any commercial land treatment facility;
section 505 B.

Section 507. Location Criteria

A. Commercial facilities and transfer stations may not be located in any area:

SPECIAL CONDITIONS	RESTRICTED DISTANCE
Land treatment of waste Type 06:	
≤ 113 mg/kg total benzene (MPC)	1,000'
Not tested or > 113 mg/kg total benzene (MPC)	2,000'
Land treatment of waste Type 12:	
≤ 3198 mg/kg total benzene (MPC)	2,000'

> 3198 mg/kg total benzene (MPC)	(banned)
Land treatment of all other E&P waste types	1,000'

Section 515.F.4.b. Specific plans for preventing or minimizing air emissions from sources such as volatilization of organic materials (e.g., benzene) and /or hydrogen sulfide in E&P Waste, particulate matter (dust) carried by the wind, periodic removal and subsequent handling of free oil, and chemical reactions (e.g. production of hydrogen sulfide from sulfur-bearing E&P Wastes);

APPENDIX B

0.05 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION ACADIA PARISH SOILS

DATA ENTRY SHEET

SL-ADV
Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES: X

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	5.00E+01	Benzene

MORE ↓

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28): Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum B, (Enter value or 0) h_B (cm)	ENTER Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SIL		

MORE ↓

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SIL	1.49	0.439	0.18	0.0224	SICL	1.37	0.482	0.198	0.0224	SIC	1.38	0.481	0.216	0.0224

MORE ↓

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R (µg/kg)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.259	0.284	0.265	0.307	2.88E-09	0.798	2.30E-09	4,000	5.00E+01	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	5.08E-03	5.73E-03	4.57E-03	5.08E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} (µg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, exp(Pe^f) (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (µg/m^3)	Finite source β term (unitless)	Finite source ψ term ($sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	6.77E+03	0.10	8.33E+01	5.08E-03	4.00E+02	#NUM!	NA	NA	1.80E+00	8.53E-08	2.05E+07	YES

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ (µg/m^3)	Finite source bldg. conc., $C_{building}$ (µg/m^3)	Final finite source bldg. conc., $C_{building}$ (µg/m^3)	Unit risk factor, URF ($µg/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	1.75E-01	NA	1.75E-01	7.8E-06	3.0E-02

END

RESULTS SHEET

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C_{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
NA	NA	NA	2.71E+06	NA

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
5.6E-07	5.6E-03

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL DOWN TO "END"

END

APPENDIX C

113 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION ACADIA PARISH SOILS

DATA ENTRY SHEET

SL-ADV Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES [ ]

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES [X]

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	1.13E+05	Benzene

MORE

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28) Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, (Enter value or 0) h_B (cm)	Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SIL		

MORE

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SIL	1.49	0.439	0.18	0.0224	SiCL	1.37	0.482	0.198	0.0224	SiC	1.38	0.481	0.216	0.0224

MORE

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R ($\mu g/kg$)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.259	0.284	0.265	0.307	2.88E-09	0.798	2.30E-09	4,000	1.13E+05	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	5.08E-03	5.73E-03	4.57E-03	5.08E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source β term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	1.53E+07	0.10	8.33E+01	5.08E-03	4.00E+02	#NUM!	NA	NA	1.80E+00	8.53E-08	2.05E+07	YES

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Final finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	3.95E+02	NA	3.95E+02	7.8E-06	3.0E-02

END

RESULTS SHEET

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C_{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
NA	NA	NA	2.71E+06	NA

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
1.3E-03	1.3E+01

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL DOWN TO "END"

END

APPENDIX D

912 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION ACADIA PARISH SOILS

DATA ENTRY SHEET

SL-ADV Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES: X

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES:

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	9.12E+05	Benzene

MORE

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28): Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, (Enter value or 0) h_B (cm)	Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SIL		

MORE

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SIL	1.49	0.439	0.18	0.0224	SICL	1.37	0.482	0.198	0.0224	SIC	1.38	0.481	0.216	0.0224

MORE

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1
				Used to calculate risk-based soil concentration.	

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R ($\mu g/kg$)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.259	0.284	0.265	0.307	2.88E-09	0.798	2.30E-09	4,000	1.00E+00	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	5.08E-03	5.73E-03	4.57E-03	5.08E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source β term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	1.35E+02	0.10	8.33E+01	5.08E-03	4.00E+02	#NUM!	NA	NA	1.80E+00	8.53E-08	2.05E+07	YES

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Final finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	3.50E-03	NA	3.50E-03	7.8E-06	3.0E-02

END

APPENDIX E

0.05 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION LAFOURCHE PARISH SOILS

DATA ENTRY SHEET

SL-ADV Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES [ ]

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES [X]

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	5.00E+01	Benzene

MORE ↓

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28) Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, (Enter value or 0) h_B (cm)	Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SIL		

MORE ↓

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SIL	1.49	0.439	0.18	0.0224	SL	1.62	0.387	0.103	0.0224	C	1.43	0.459	0.215	0.0224

MORE ↓

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R (µg/kg)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.259	0.284	0.244	0.307	2.88E-09	0.798	2.30E-09	4,000	5.00E+01	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	5.08E-03	8.88E-03	3.81E-03	5.28E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} (µg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, exp(Pe^f) (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (µg/m^3)	Finite source β term (unitless)	Finite source ψ term ($sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	6.82E+03	0.10	8.33E+01	5.08E-03	4.00E+02	#NUM!	NA	NA	1.83E+00	8.62E-08	2.06E+07	YES

Finite source indoor attenuation coefficient, <α> (unitless)	Mass limit bldg. conc., $C_{building}$ (µg/m^3)	Finite source bldg. conc., $C_{building}$ (µg/m^3)	Final finite source bldg. conc., $C_{building}$ (µg/m^3)	Unit risk factor, URF ($\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	1.81E-01	NA	1.81E-01	7.8E-06	3.0E-02

END

RESULTS SHEET

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C_{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
NA	NA	NA	2.69E+06	NA

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
5.8E-07	5.8E-03

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL DOWN TO "END"

END

APPENDIX F

113 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION LAFOURCHE PARISH SOILS

DATA ENTRY SHEET

SL-ADV Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES [ ]

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES [X]

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	1.13E+05	Benzene

MORE

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28) Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, (Enter value or 0) h_B (cm)	Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SIL		

MORE

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SIL	1.49	0.439	0.18	0.0224	SL	1.62	0.387	0.103	0.0224	C	1.43	0.459	0.215	0.0224

MORE

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP (g/cm-s^2)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R (µg/kg)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.259	0.284	0.244	0.307	2.88E-09	0.798	2.30E-09	4,000	1.13E+05	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	5.08E-03	8.88E-03	3.81E-03	5.28E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} (µg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (µg/m^3)	Finite source β term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	1.54E+07	0.10	8.33E+01	5.08E-03	4.00E+02	#NUM!	NA	NA	1.83E+00	8.62E-08	2.06E+07	YES

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ (µg/m^3)	Finite source bldg. conc., $C_{building}$ (µg/m^3)	Final finite source bldg. conc., $C_{building}$ (µg/m^3)	Unit risk factor, URF $(µg/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	4.10E+02	NA	4.10E+02	7.8E-06	3.0E-02

END

RESULTS SHEET

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C_{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
NA	NA	NA	2.69E+06	NA

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
1.3E-03	1.3E+01

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL DOWN TO "END"

END

APPENDIX G

912 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION LAFOURCHE PARISH SOILS

DATA ENTRY SHEET

SL-ADV Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES [ ]

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES [X]

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	9.12E+05	Benzene

MORE

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28): Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum B, (Enter value or 0) h_B (cm)	ENTER Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SIL		

MORE

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SIL	1.49	0.439	0.18	0.0224	SL	1.62	0.387	0.103	0.0224	C	1.43	0.459	0.215	0.0224

MORE

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R ($\mu g/kg$)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.259	0.284	0.244	0.307	2.88E-09	0.798	2.30E-09	4,000	9.12E+05	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} ($atm\text{-}m^3/mol$)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	5.08E-03	8.88E-03	3.81E-03	5.28E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source β term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	1.24E+08	0.10	8.33E+01	5.08E-03	4.00E+02	#NUM!	NA	NA	1.83E+00	8.62E-08	2.06E+07	YES

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Final finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	3.31E+03	NA	3.31E+03	7.8E-06	3.0E-02

END

RESULTS SHEET

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C_{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
NA	NA	NA	2.69E+06	NA

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
1.1E-02	1.1E+02

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL DOWN TO "END"

END

APPENDIX H

0.05 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION OUACHITA PARISH SOILS

DATA ENTRY SHEET

SL-ADV Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES: X

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	5.00E+01	Benzene

MORE

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28): Thickness of soil stratum A, h_A (cm)	Thickness of soil stratum B, (Enter value or 0) h_B (cm)	Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SL		

MORE

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SL	1.62	0.387	0.103	0.0224	L	1.59	0.399	0.148	0.0224	SCL	1.63	0.384	0.146	0.0224

MORE

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R ($\mu g/kg$)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.284	0.251	0.238	0.184	6.06E-09	0.901	5.46E-09	4,000	5.00E+01	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	8.88E-03	5.54E-03	5.01E-03	5.74E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source β term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	7.13E+03	0.10	8.33E+01	8.88E-03	4.00E+02	#NUM!	NA	NA	1.90E+00	8.59E-08	2.14E+07	YES

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ ($\mu g/m^3$)	Finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Final finite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	2.07E-01	NA	2.07E-01	7.8E-06	3.0E-02

END

RESULTS SHEET

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C_{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
NA	NA	NA	2.58E+06	NA

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
6.6E-07	6.6E-03

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL DOWN TO "END"

END

APPENDIX I

113 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION OUACHITA PARISH SOILS

DATA ENTRY SHEET

SL-ADV Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES [ ]

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES [X]

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	1.13E+05	Benzene

MORE ↓

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28): Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum B, (Enter value or 0) h_B (cm)	ENTER Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SL		

MORE ↓

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SL	1.62	0.387	0.103	0.0224	L	1.59	0.399	0.148	0.0224	SCL	1.63	0.384	0.146	0.0224

MORE ↓

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R (µg/kg)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.284	0.251	0.238	0.184	6.06E-09	0.901	5.46E-09	4,000	1.13E+05	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	8.88E-03	5.54E-03	5.01E-03	5.74E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} (µg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, exp(Pe^f) (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (µg/m^3)	Finite source β term (unitless)	Finite source ψ term $(sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	1.61E+07	0.10	8.33E+01	8.88E-03	4.00E+02	#NUM!	NA	NA	1.90E+00	8.59E-08	2.14E+07	YES

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ (µg/m^3)	Finite source bldg. conc., $C_{building}$ (µg/m^3)	Final finite source bldg. conc., $C_{building}$ (µg/m^3)	Unit risk factor, URF $(µg/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	4.67E+02	NA	4.67E+02	7.8E-06	3.0E-02

END

RESULTS SHEET

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C_{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
NA	NA	NA	2.58E+06	NA

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
1.5E-03	1.5E+01

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL DOWN TO "END"

END

APPENDIX J

912 MG/KG BENZENE SOIL CONCENTRATION CALCULATIONS FOR INDOOR VAPOR INTRUSION OUACHITA PARISH SOILS

SL-ADV Version 3.1; 02/04

Reset to Defaults

CALCULATE RISK-BASED SOIL CONCENTRATION (enter "X" in "YES" box)

YES [ ]

OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL SOIL CONCENTRATION (enter "X" in "YES" box and initial soil conc. below)

YES [X]

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial soil conc., C_R (µg/kg)	Chemical
71432	9.12E+05	Benzene

MORE

ENTER Average soil temperature, T_S (°C)	ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Depth below grade to top of contamination, L_t (cm)	ENTER Depth below grade to bottom of contamination, (enter value of 0 if value is unknown) L_b (cm)	ENTER Totals must add up to value of L_t (cell G28): Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum B, (Enter value or 0) h_B (cm)	ENTER Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
22.68	15	91.44	152.4	30.48	30.48	30.48	SL		

MORE

ENTER Stratum A SCS soil type (Lookup Soil Parameters)	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum A soil organic carbon fraction, f_{oc}^A (unitless)	ENTER Stratum B SCS soil type (Lookup Soil Parameters)	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum B soil organic carbon fraction, f_{oc}^B (unitless)	ENTER Stratum C SCS soil type (Lookup Soil Parameters)	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)	ENTER Stratum C soil organic carbon fraction, f_{oc}^C (unitless)
SL	1.62	0.387	0.103	0.0224	L	1.59	0.399	0.148	0.0224	SCL	1.63	0.384	0.146	0.0224

MORE

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)	ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
30.48	40	1000	1000	366	0.1	0.25	5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)	ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)
70	30	30	350	1.0E-06	1

Used to calculate risk-based soil concentration.

END

INTERMEDIATE CALCULATIONS SHEET

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Initial soil concentration used, C_R (µg/kg)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	76.44	0.284	0.251	0.238	0.184	6.06E-09	0.901	5.46E-09	4,000	9.12E+05	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} (atm-m^3/mol)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)	Convection path length, L_p (cm)
1.00E+06	4.00E-04	15	7,991	4.98E-03	2.05E-01	1.79E-04	8.88E-03	5.54E-03	5.01E-03	5.74E-03	76.44	15

Soil-water partition coefficient, K_d (cm^3/g)	Source vapor conc., C_{source} (µg/m^3)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, exp(Pe^f) (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ (µg/m^3)	Finite source β term (unitless)	Finite source ψ term ($sec)^{-1}$	Time for source depletion, τ_D (sec)	Exposure duration > time for source depletion (YES/NO)
1.32E+00	1.30E+08	0.10	8.33E+01	8.88E-03	4.00E+02	#NUM!	NA	NA	1.90E+00	8.59E-08	2.14E+07	YES

Finite source indoor attenuation coefficient, $<\alpha>$ (unitless)	Mass limit bldg. conc., $C_{building}$ (µg/m^3)	Finite source bldg. conc., $C_{building}$ (µg/m^3)	Final finite source bldg. conc., $C_{building}$ (µg/m^3)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
NA	3.77E+03	NA	3.77E+03	7.8E-06	3.0E-02

END

RESULTS SHEET

RISK-BASED SOIL CONCENTRATION CALCULATIONS:

Indoor exposure soil conc., carcinogen (µg/kg)	Indoor exposure soil conc., noncarcinogen (µg/kg)	Risk-based indoor exposure soil conc., (µg/kg)	Soil saturation conc., C_{sat} (µg/kg)	Final indoor exposure soil conc., (µg/kg)
NA	NA	NA	2.58E+06	NA

INCREMENTAL RISK CALCULATIONS:

Incremental risk from vapor intrusion to indoor air, carcinogen (unitless)	Hazard quotient from vapor intrusion to indoor air, noncarcinogen (unitless)
1.2E-02	1.2E+02

MESSAGE AND ERROR SUMMARY BELOW: (DO NOT USE RESULTS IF ERRORS ARE PRESENT)

SCROLL DOWN TO "END"

END

APPENDIX K
GLOSSARY OF TERMS

GLOSSARY OF TERMS

Acute Exposure	Contact with a substance that occurs once or for a short period of time.
ATSDR	Agency for Toxic Substances & Disease Registry
Bentonite	Material used in the plugging and abandonment of a temporary well.
Benzene	A colorless liquid hydrocarbon that is highly inflammable and carcinogenic. It is the simplest of the aromatic compounds. Naturally and unnaturally occurring in E&P waste.
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
Chronic Exposure	Contact with a substance that occurs over a long period of time and normally lasts longer than one year.
Commercial facility	A legally permitted E&P Waste storage, treatment and/or disposal facility which receives, treats, reclaims, stores, and/or disposes of E&P Waste for a fee or other considerations.
Contamination	The introduction of substances or contaminants into a groundwater aquifer, a USDW or soil in such quantities as to render them unusable for their intended purposes.
Crude Oil	Unrefined petroleum.
Emergency Pit	Lined or earthen pits used to periodically collect produced water and other nonhazardous oilfield waste fluids only during emergency incidents, rupture or failure of other facilities.
Exploration and Production waste	Drilling wastes, salt water, and other wastes associated with the exploration, development, or production of crude oil or natural gas wells and which is not regulated by the provisions of, and, therefore, exempt form the Louisiana Hazardous Waste Regulations and the Federal Resource Conservation and Recovery Act.
Fraction organic carbon	Fraction organic carbon (foc) is a dimensionless (g(carbon)/g(soil)), mass measure of the quantity of soil organic carbon relative to soil media. The measure is used to estimate the capacity of a soil to adsorb or bind certain contaminants.
Hydrocarbons	An organic substance that consists entirely of hydrogen and carbon and is found in crude oil.

Land Treatment	A dynamic process involving the controlled application of E&P Waste onto or into the aerobic surface soil horizon in open cells by a commercial land treatment facility, accompanied by continued monitoring and management, to alter the physical, chemical, and biological state of the E&P Waste. Site, soil, climate, and biological activity interact as a system to degrade and immobilize E&P Waste constituents thereby rendering the area suitable for the support of vegetative growth and providing for beneficial future land use or to meet the reuse criteria.
Manufactured Liner	Any man-made synthetic material of sufficient size and qualities to sustain a hydraulic conductivity no greater than 1 $x10^{-7}$ cm/sec after installation and which is sufficiently reinforced to withstand normal wear and tear associated with the installation and pit use without damage to the liner or adverse affect on the quality thereof.
MPC	Maximum permissible concentration
Negative pressure	A pressure less than that of the surrounding area.
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
Passive closure	Pit closure where closure would create a greater adverse environmental impact than if the pit were allowed to remain unreclaimed.
PEL	Permissible exposure limit
Pit	A natural topographic depression or man-made excavation used to hold produced water or other nonhazardous oilfield waste, hydrocarbon storage brine, or mining water.
Pit Closure	The removal of E&P waste from a pit by utilizing onsite land treatment, burial, solidification or other techniques.
Pit liner	Impermeable substance that lines a pit and has a hydraulic conductivity of 1 $x10^{-7}$.
Produced water	Liquids and suspended particulate matter that is obtained by processing fluids brought to the surface in conjunction with the recovery of oil and gas from underground geologic formations, with underground storage of hydrocarbons, or with solution mining for brine.

Production Pit	Either earthen or lined storage pits for collecting NOW sediment periodically cleaned from tanks and other producing facilities. for storage of produced water or other nonhazardous oilfield wastes produced from the operation of oil gas facilities, or used in conjunction with hydrocarbon storage and solution mining operation.
Promulgate	To make known or public.
Regulation	A rule or order issued by a government agency and often having the force of law.
Remediation	The removal of pollution or contaminants from environmental media such as soil, groundwater, sediment, or surface water for the general protection of human health and the environment or from a brownfield site intended for redevelopment.
Reserve Pits	Temporary earthen pits used to store only those materials used or generated in drilling and workover operations. (Statewide Order 29-B)
STEL	Short-term exposure limit, a 15-minute time weight average exposure that should not be exceeded
Soil dry bulk density	Bulk density is a measure of the weight of the soil per unit volume.
Soil vapor permeability	Air vapor passage through the soil media.
Soil-building pressure differential	The pressure difference between the soil and the building.
TCLP	Toxicity characteristic leaching procedure
TWA	Time weighted average, concentration of for a normal 8-hour workday or a 40-hour work week.
Toxicity	The degree to which something is able to produce illness or damage to an exposed organism.
Volatile	Characteristic of a chemical that evaporates quickly at room temperatures.

VITA

Daniel Wascom is a native of Baton Rouge, Louisiana. He is a graduate of The Dunham School. Daniel attended Northwestern State University and graduated in 2003. While he was attending Northwestern State University, he was a student athlete and graduated with a Bachelor of Science. Daniel currently works for an environmental consulting company in Baton Rouge. His professional interests include management of environmental projects pertaining to the oil and gas industry.